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(54) Combined cycle apparatus for synthesis gas production

(57) Hydrocarbon fuel, oxygen and steam are partially burned in a combustor 13 to produce a high temperature and cause reaction of the remainder. The products of combustion and reaction, after passing through a gas turbine 14 and subsequently through a heat exchanger 70 to produce steam are processed through a condenser 76 to remove the liquid component. In one embodiment, Fig. 3 (not shown), the gases are thereafter delivered through a compressor (102) and a cooling tank (104) to provide hydrogen and carbon monoxide which are reacted in a process reactor (110) to produce useful hydrocarbon products, an example of which is methanol. The steam produced at the exchanger 70 is used to drive a steam turbine 60. Electric power is produced by a generator 40 driven by the gas and steam turbines. The generator output is used to operate all of the motive means which process gases in the cycle. Excess electric power and steam are available for cogeneration use.

FIG. 1

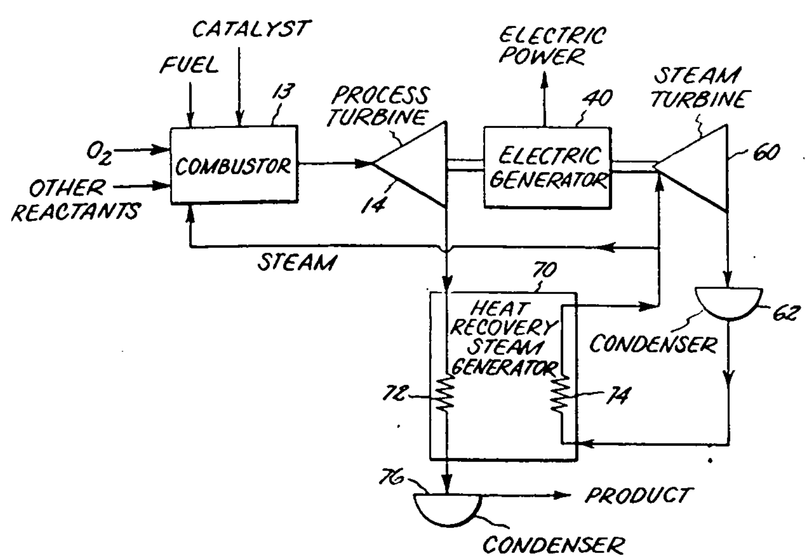

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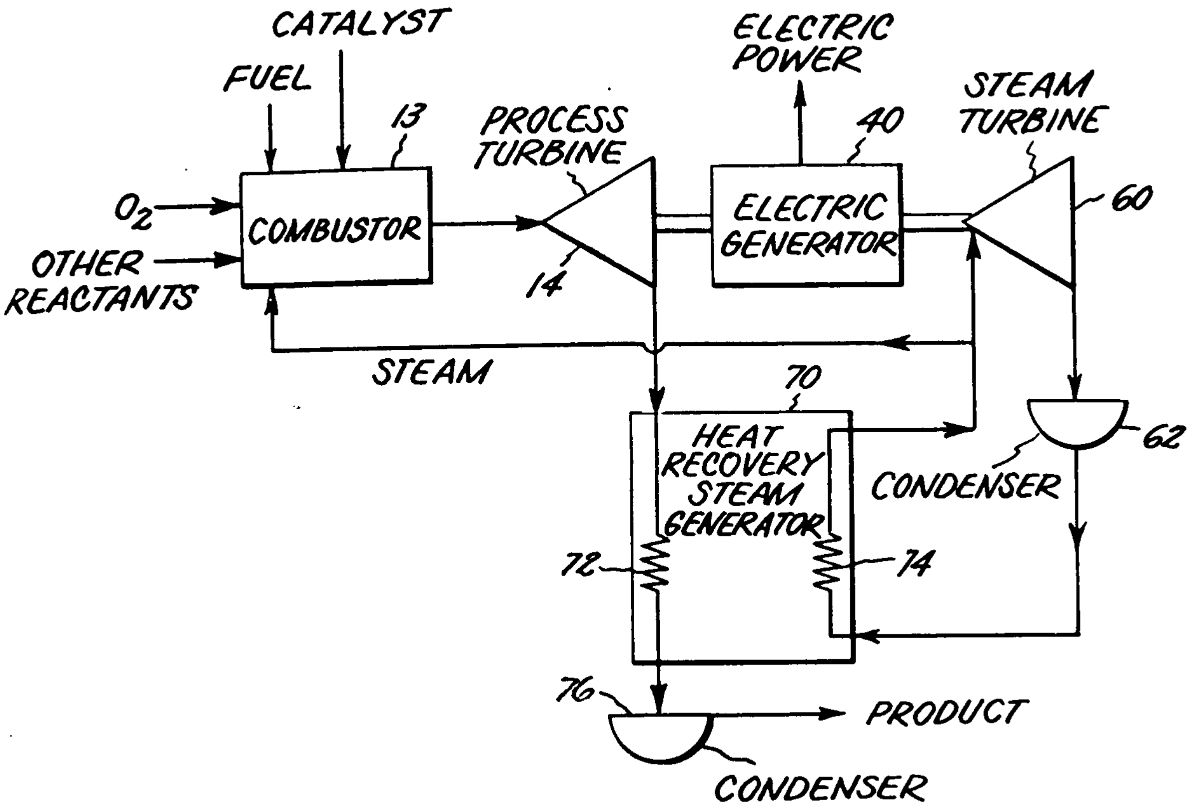
FIG. 1


CATALYST
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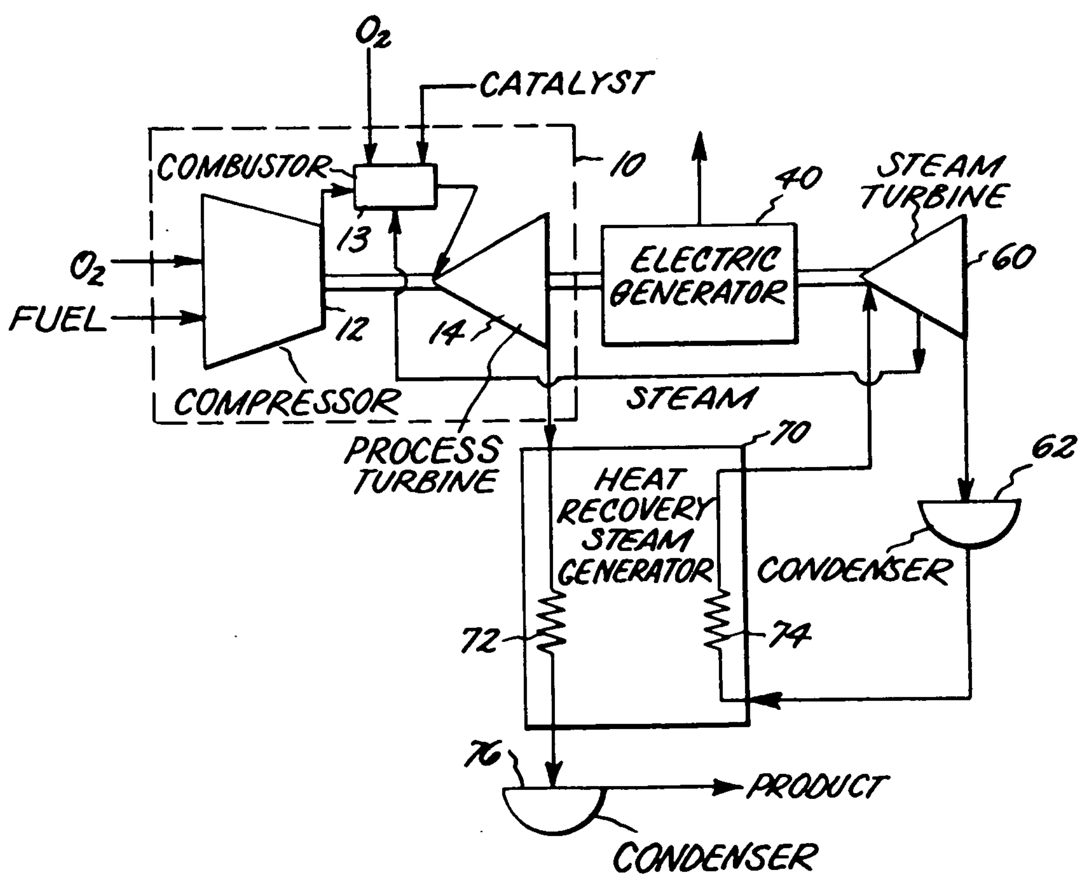
PROCESS TURBINE
ELECTRIC POWER
40
STEAM TURBINE
O_2
COMBUSTOR
ELECTRIC GENERATOR
60
OTHER REACTANTS
14
STEAM
70
HEAT RECOVERY STEAM GENERATOR
62
CONDENSER
72
74
76
PRODUCT
CONDENSER

FIG. 2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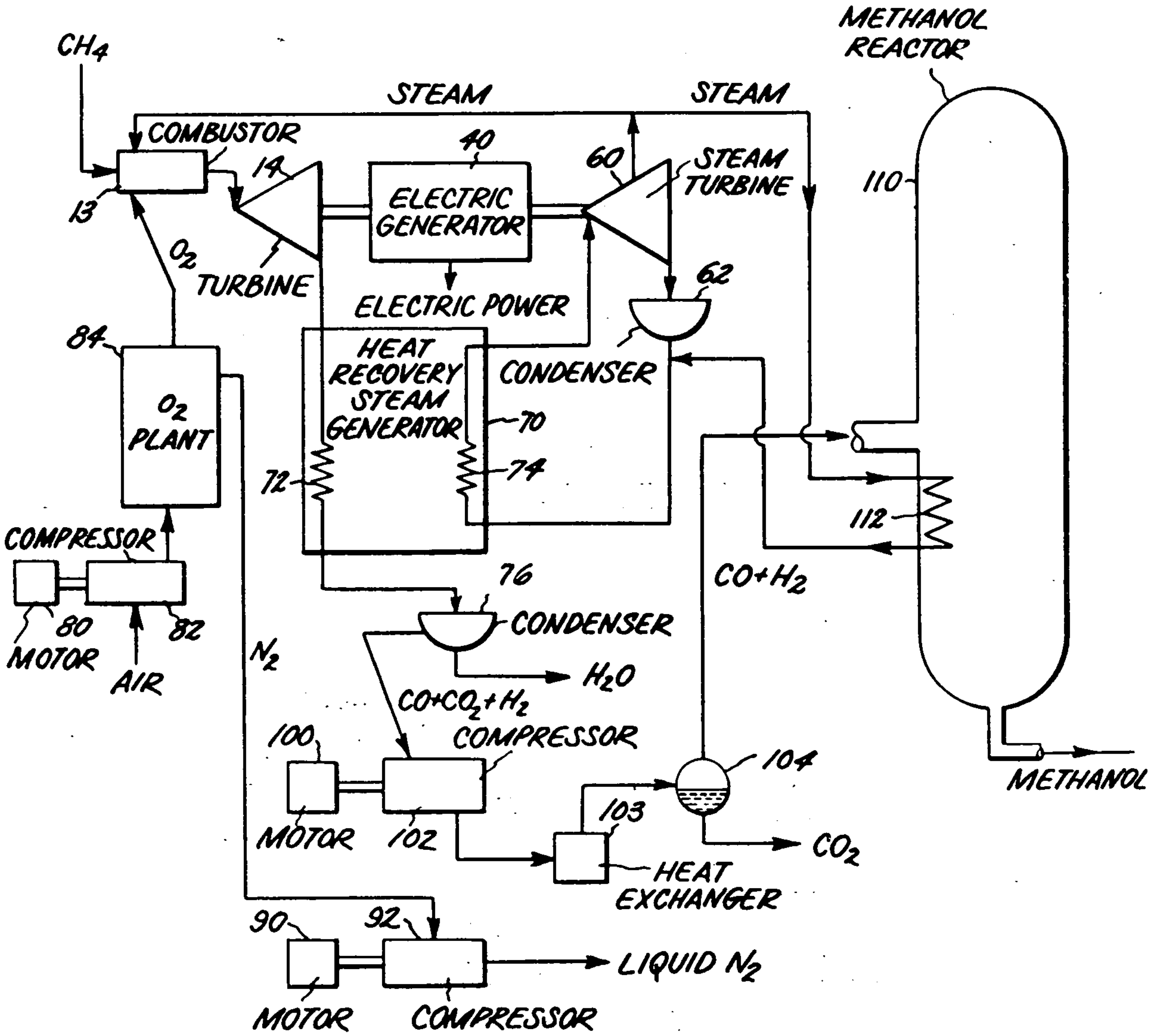
COMBUSTOR
10
40
STEAM TURBINE
13
60
O_2
ELECTRIC GENERATOR
FUEL
12
14
COMPRESSOR
STEAM
PROCESS TURBINE
70
62
HEAT RECOVERY STEAM GENERATOR
CONDENSER
72
74
76
PRODUCT
CONDENSER

FIG. 3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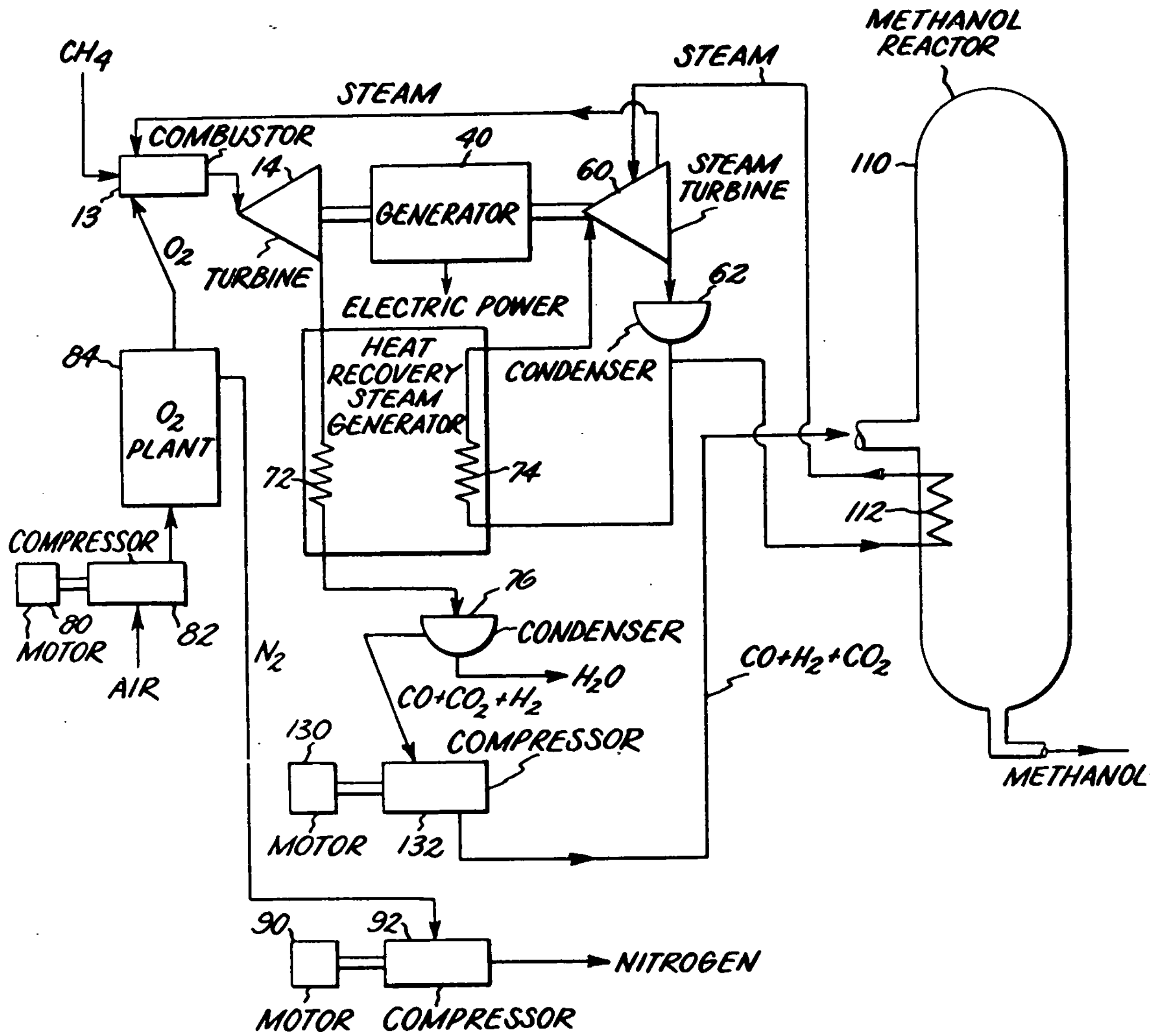
CH4
STEAM
STEAM
COMBUSTOR
40
14
60
STEAM TURBINE
110
13
ELECTRIC GENERATOR
O2
TURBINE
62
ELECTRIC POWER
84
HEAT RECOVERY STEAM GENERATOR
CONDENSER
O2 PLANT
70
72
74
112
COMPRESSOR
76
CO+H2
80
82
CONDENSER
MOTOR
AIR
N2
H2O
CO+CO2+H2
100
COMPRESSOR
104
METHANOL
103
MOTOR
102
CO2
HEAT EXCHANGER
90
92
LIQUID N2
MOTOR
COMPRESSOR

FIG. 4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STEAM
CH_4
STEAM
COMBUSTOR
40
14
60
STEAM TURBINE
110
13
GENERATOR
O_2
TURBINE
62
ELECTRIC POWER
84
HEAT RECOVERY STEAM GENERATOR
CONDENSER
O_2 PLANT
72
74
112
COMPRESSOR
76
80
82
CONDENSER
MOTOR
N_2
H_2O
$CO+H_2+CO_2$
AIR
$CO+CO_2+H_2$
130
COMPRESSOR
METHANOL
MOTOR
132
90
92
NITROGEN
MOTOR
COMPRESSOR

SPECIFICATION

Combined cycle apparatus for synthesis gas production

Background of the invention

This invention relates to the use of gas turbine components and the manufacture of useful byproducts thereby. In particular, a combustor and a process turbine in a combined cycle configuration are employed to generate large amounts of carbon monoxide and hydrogen which may be employed as useful hydrocarbon precursors such as methanol in addition to the usual production of electrical power.

The mixture of carbon monoxide and hydrogen in accord with this invention is generally used as a gas for the synthesis of other compounds, particularly hydrocarbons. For this reason, the gaseous mixture of carbon monoxide and hydrogen is generally referred to herein as synthesis gas, or, more briefly, as syngas. Syngas has been employed in the past in the production of methanol, both in high-pressure and in low-pressure processes. For example, see "Technology of Lugri's Low-Pressure Methanol Process" by E. Supp on page 430 of *Chem Tech* in July 1973. As described therein, syngas may also include carbon dioxide as a constituent. However, these processes do not take complete advantage of the thermal and mechanical energies contained in the reaction products and, accordingly, their overall plant energy efficiencies can be improved.

Gas turbines have been employed in the past primarily for the production of electrical energy where fuel is plentiful and water is in short supply and otherwise for load peaking purposes or for the purpose of driving relatively small pumps or compressors or other related mechanical devices. Gas turbines have also been employed in combined cycle plants which also include steam turbines either driven on the same shaft or on a separate shaft from the gas turbine. In a combined cycle plant, the hot exhaust gases from the gas turbine are fed into a heat recovery steam generator to generate steam to drive a steam turbine which also drives a generator for the production of electric energy. These combined cycle plants are extremely efficient but have not been heretofore employed for the purpose of producing various gaseous byproducts, including syngas.

In general, gas turbines operate in a configuration comprising a compressor, a combustor and a load or process turbine. In the present invention, a compressor may be provided, if desired, in which case, the turbine part of the gas turbine is referred herein as a load turbine. In those situations in which a compressor is not required, a combustor and a turbine are employed, in which case, the turbine is referred to herein as a process turbine. In either event, the actual apparatus employed may be identical to the units employed in commercially available, gas turbine power plants.

Since commercially available gas turbines generally operate in an "open cycle" in which they are generally open to the atmosphere both at intake and exhaust, a significant amount of nitrogen is introduced by the compressor into the flow path through the turbine. As a result, certain nitrogen oxides may be produced and exhausted into the atmosphere. In the past, steam has, on occasion, been injected into the gas turbine compressor for the purpose of controlling formation of nitrogen oxides. In the production of syngas, according to the methods and apparatus of the present invention, however, nitrogen is not normally a desirable constituent of the flow through the turbine, particularly in large quantities.

While the production of syngas is itself a desirable goal, because syngas is useful in a number of chemical processes, it is nonetheless also desirable to convert syngas to such useful products as methanol. There are several reasons for this. First is the fact that the energy density (as measured in BTUs per volume of methanol) is relatively high compared to gaseous methane and, therefore, makes methanol an easily transportable liquid fuel. In fact, in many places around the world, methanol is used as a substitute for gasoline, kerosene and fuel oil. Second, it is also known that it is possible to convert methanol directly to gasoline. See, for example, the article in "Large Chemical Plants", by W. Lee et al., published by Elsevier Scientific Publishing Compamy, Amsterdam, The Netherlands (page 71 and following). Because natural gas may be employed in the production of syngas, efficient and economic methods and apparatus which are employable to produce syngas from methane or natural gas are highly desirable and form a key link in a transportation energy economy based on the conversion of natural gas to syngas, the conversion of syngas to methanol and finally the conversion of methanol to gasoline. Such methods and apparatus are also extremely important in light of recent discoveries and evidence of the abundance of deep earth natural gas supplies. Even if the deep earth natural gas assumptions prove to be optimistic, it is nonetheless clear that at the present time much natural gas which is produced during oil well operations throughout the world is wasted. In the oil fields in the Middle East and elsewhere much of this natural gas is simply ignited and flared off, often for lack of an economical transportation structure to supply this gas to areas of high population density where it may be used. It is, therefore, seen that the methods and apparatus which may be employed for the conversion of this natural gas to products such as methanol or gasoline are highly desirable since transportation structures for these fuels either already exist or may be assembled economically and quickly.

Summary of the invention

In accordance with a preferred embodiment of the present invention gas turbine apparatus for

producing syngas as a useful byproduct comprises a combustor for partial burning to cause a high temperature suitable for substantially complete reaction of the hydrocarbon fuel in the presence of steam and oxygen; a turbine driven by gases exhausted by said combustor; a means of recovering the heat from the gas turbine exhaust (steam generation) and a means for condensing water and/or carbon dioxide from gases exhausted from the turbine, producing a mixture of gases including carbon monoxide and hydrogen. In accordance with another embodiment where natural gas pressure from the well are not used, the combustor and turbine may be combined with a compressor to compress the natural gas and steam, in which case a complete gas turbine unit such as a General Electric MS7001E may be employed to effect the production of the syngas. Furthermore, the preferred embodiment of the invention uses the gas turbine in a combined cycle such as a General Electric STAG™-100 configuration in which the thermal and mechanical energies of the reaction products may be employed to serve several functions. For example, steam is generated for use in the combustor. Mechanical energy from the turbine is employed to drive either compressors and/or generators which may in turn be connected to a part of means for liquefaction of air to provide oxygen which is used in the combustor. The apparatus of the present invention is particularly useful in the conversion of methane to syngas for further processing to useful hydrocarbon products such as methanol. As a result of the operation of the cycle involving combustion of methane as described herein, the apparatus of the present invention also produces quantities of carbon dioxide and the air liquefaction means also provides a readily accessible source of nitrogen.

Both carbon dioxide and nitrogen are useful in the tertiary recovery of crude oil deposits. Accordingly, since methane is the primary constituent of natural gas, and since natural gas is often found along with oil deposits, the apparatus of the present invention may not only be used for the on-site conversion of natural gas to syngas, methanol and serve to provide the input for the conversion of methanol to gasoline, but also for the further recovery of tertiary crude oil deposits located at or near the natural gas source. There is also disclosed herein a method for operating a gas turbine to produce syngas by partial burning to cause reaction of a hydrocarbon fuel in the presence of oxygen and steam in a combustor to produce a mixture of exhaust gases which drive a load turbine which drives a turbogenerator. Water and/or carbon dioxide and heat is then removed from the gases exhausted from the turbine.

Accordingly, it is an object of the present invention to provide gas turbine apparatus for the efficient and economical production of syngas from natural gas.

It is also an object of the present invention to provide gas turbine apparatus for the conversion of various hydrocarbon fuels to methanol.

It is a still further object of the present invention to provide a method for operating a gas and steam turbine combined cycle to produce a variety of useful exhaust products.

It is also an object of the present invention to provide a method for the production of syngas and methanol.

It is also an object of the present invention to provide an apparatus for the production of electrical energy and products for the tertiary recovery of crude oil as a byproduct of the production of syngas and methanol.

Description of the Figures

The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of practice, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

Figure 1 is a schematic diagram illustrating a combined cycle embodiment of the present invention.

Figure 2 is a schematic diagram similar to Figure 1 in which a compressor is employed.

Figure 3 is a schematic diagram illustrating the use of combined cycle as in Figure 1 in combination with a methanol reactor.

Figure 4 is a schematic diagram illustrating another embodiment of the present invention similar to Figure 3 except that in this embodiment carbon dioxide is not removed from the output products of the gas turbine prior to its introduction into a methanol reactor.

Detailed description of the invention

Figure 1 illustrates one embodiment of the invention in which a combined cycle configuration is employed. The combined cycle configuration is a preferred embodiment of the present invention. In particular, combustor 13 receives hydrocarbon fuel, oxygen and steam which are partially burned therein to produce a high temperature to cause substantially complete reaction of the hydrocarbon fuel with the oxygen and steam to produce a large volume of gases including carbon monoxide and hydrogen which are permitted to expand through process turbine 14. Combustor 13 and turbine 14 typically are similar to a conventional utility gas turbine such as a General Electric MS7001E without the compressor stage. For the purpose of generating syngas from steam, oxygen and hydrocarbon fuel, the compressor is not required since the steam extracted from steam turbine 60 is already provided at suitable pressure. Also the hydrocarbon fuel (natural gas) is normally supplied at a suitable pressure delivered directly by the gas well or from a pipeline. The oxygen supplied to the system is normally compressed in a special compressor subsequent to separation from air. However, it

may be desirable to inject the fuel into the combustor 13 under pressure provided by auxiliary compressors for special cases where the natural gas is at low pressure. the combustion gas products expand through process turbine 14 which drives electric generator 40, thereby producing electric power which may be sold commercially and/or employed on site to drive other devices such as the motors shown in Figures 3 and 4, which are discussed with reference thereto.

To take advantage of combined cycle efficiencies, exhaust gases from process turbine 14 are introduced into gas flow circuit 72 of heat recovery steam generator 70. Water flowing in circuit 74 of heat recovery steam generator (HRSG) 70 receives heat from gases flowing in circuit 72 and is vaporized into steam to drive steam turbine 60. Steam turbine 60 is preferably also connected to electric generator 40 or it may drive a separate generator or other mechanical devices such as compressors and pumps. It is additionally important to note that steam from the steam turbine 60 is provided to combustor 13. Additionally, steam exhausted from steam turbine 60 is condensed back to liquid in condenser 62. Condenser 62 is typically provided with an independent flow of cooling water therethrough for the purpose of forming condensate which is then recycled to circuit 74 in HRSG 70. Condenser 76, operating in the same manner as condenser 62, operates to remove steam (water vapor) from the gaseous output of the process turbine 14. In the manufacture of syngas, using steam, oxygen and hydrocarbon fuel, the resultant product from condenser 76 typically is a mixture essentially comprising carbon monoxide, hydrogen carbon dioxide and a small amount of water vapor. It may also be desirable under certain circumstances to further process this gaseous product to remove the carbon dioxide.

While the apparatus described above and shown in Figure 1 has been particularly illustrated for the production of syngas or a mixture of syngas and carbon dioxide, other reaction processes may be carried out with the combined cycle apparatus shown. In particular, one or more catalysts may be introduced into combustor 13 to enhance the production of syngas. Furthermore, other reactants may also be introduced to cause entirely different thermal chemical reactions to occur and, accordingly, to produce entirely different reaction products. Furthermore, the catalyst does not necessarily have to be introduced into combustor 13 but may instead be disposed in a more or less permanent form elsewhere in the gas path of the combined cycle.

The apparatus of Figure 1 possesses a number of significant advantages, not the least of which is its high overall energy efficiency. The combined cycle configuration provides an extremely integrated and high level of co-operation between the steam and gas turbine components. It is this co-operation which contributes to overall plant energy efficiency.

As discussed above, for the production of syngas or syngas also containing carbon dioxide, a preferred hydrocarbon fuel is natural gas or methane which is the primary constituent of natural gas. Much natural gas is frequently wasted by being flared off at oil well sites. The apparatus of the present invention provides a relatively compact plant which may, for example, be mounted on a barge and floated to service one or more off-shore drilling stations, as well as be used at on-shore fields.

While the invention is described herein with respect to the use of methane or natural gas (of which methane is a principal component) other hydrocarbon fuels, gaseous or liquid may be utilized. Other suitable fuels include hydrocarbons of the paraffin series from CH_4 (methane) to C_6H_14; also, hydrocarbons of the olefin series and the aromatic series.

Figure 2 is similar to Figure 1 except that compressor 12 is employed to supply pressurized gaseous fuel and/or other constituents of the combustion process to combustor 13. In this configuration, compressor 12, combustor 13 and turbine 14 (now referred to as a load turbine) constitute a state of the art gas turbine 10. In Figure 1, only the combustor and turbine portion of a complete gas turbine are needed to perform the desired function. Because of the relatively large energy required to drive compressor 12, Figure 2 does not illustrate a preferred embodiment of the present invention for the production of syngas. Nonetheless, the embodiment shown in Figure 2 embodies apparatus for pressurizing the fuel required in syngas manufacture. However, for the production of other combustion products, Figure 2 may be particularly desirable especially since gas turbine 12 may be easily supplied as a conventional commercially available gas turbine such as a General Electric MS7001E gas turbine.

Figure 3 is similar to Figure 1 except that two additional supporting systems are shown. In particular, there is also shown an oxygen plant and a schematic of a methanol reactor 110 which receives the syngas output from the gas turbine combined cycle and produces steam from the exothermic syngas to methanol reaction which is available for use in the steam system.

Because the syngas reaction requires oxygen, it is preferable that an oxygen plant be located on the same site as the syngas-producing apparatus. To produce this oxygen motor 80 drives compressor 82 which receives as an input atmospheric air which is compressed and liquefied in oxygen plant 84 which supplies oxygen to combustor 13. Oxygen plant 84 includes refrigerant means to liquefy the compressed air so that it may be separated into oxygen and nitrogen by fractional distillation, for example. The compressor 82 is preferably driven by an electric motor which receives electrical energy from generator 40. Moreover, oxygen plant 84 may also supply nitrogen and other atmospheric components such as argon to

compressor 92 which is driven by motor 90, preferably driven by generator 40. Compressor 92 supplies compressed nitrogen. The compressed nitrogen is an economically desired byproduct of the operation of the syngas-producing apparatus of the present invention. The nitrogen may be sold separately as a commercial product; and the nitrogen may be used in the tertiary recovery of crude oil, particularly at those site locations for which the hydrocarbon fuel is natural gas supplied from nearby crude oil wells.

Another difference between the embodiments of Figure 3 and Figure 1 is the inclusion of methanol reactor 110 and associated apparatus for the removal of carbon dioxide from the syngas mixture prior to its introduction into methanol reactor 110 in the embodiment shown in Figure 3. In Figure 3 carbon dioxide is removed from the syngas mixture to adjust the ratio of constituents by introducing the output from condenser 76 into compressor 102 driven by motor 100. The carbon dioxide is liquefied in heat exchanger 103 and is separated from the gaseous constituents $CO+H_2$ in tank 104. Again, as pointed out above, carbon dioxide is also a useful byproduct, particularly for the recovery of tertiary crude oil. The remaining product gases, comprising essentially hydrogen and carbon monoxide, are introduced into methanol reactor 110. This methanol reactor 110 is cooled by removal of the exothermic heat of reaction by heat exchanger 112 by conversion of water therein to steam to produce additional motive steam for steam turbine 60. Methanol formed is extracted from the bottom of methanol reactor 110. It is to be noted, however, that the details of the methanol reactor, which are state of the art are not a part of the invention and the representation of reactor 110 is in schematic form only, for any suitable state-of-the-art methanol reactor such as the LURGI reactor referred to above may be used to implement the invention.

Figure 4 illustrates another embodiment of the present invention which is similar to Figure 3 except that herein carbon dioxide is not removed prior to its introduction into the methanol reactor 110. Instead, the reaction products from condenser 76 from which water is removed by the condenser, is supplied to compressor 132 driven by motor 130. Thus, this compressor supplies a mixture consisting essentially of carbon monoxide, carbon dioxide and hydrogen to methanol reactor 110. Methanol collects at the bottom of reactor 110 and is removed therefrom. Depending upon the amount of hydrogen in reactor 110 there may or may not be an excess of CO_2.

As indicated above, methanol from reactor 110 may be shipped directly using existing oil pipe lines or similar transportation facilities which are currently employed for petroleum product transport. These transportation media require a minimum of modification for the transport of raw methanol. Additionally, means may also be provided on site for the direct conversion of methanol into higher molecular weight hydrocarbons including gasoline, which may be appropriately transported from the site.

In general, the methanol reactor is typically operated at a pressure of approximately 1,000 psi and the pressure in combustor 13 is typically between approximately 8 and approximately 14 atmospheres. The mixed internal combustor temperature typically ranges between 2,000°F and 2,400°F. Moreover, instead of oxygen, other oxidizers may be employed not only for the production of syngas but also, more generically, for the production of other chemical products. Additionally, if the apparatus of the present invention is located at a remote site where the commercial sale of excess electric energy is not practical, the electrical power may be used in the electrolysis of water to produce hydrogen for additional methanol production and oxygen for use in the combustor. If the commercial sale of electrical energy is practical, then the apparatus and plant of the present invention may serve also as an additional source of commercial electric power in addition to its primary use as an extremely non-polluting energy source producing chemical fuels such as methanol and/or gasoline and/or chemical products such as syngas.

From another viewpoint, the apparatus or plant of the present invention is unique in that it provides its own artificial atmosphere for operating a gas turbine, either with or without a compressor. In particular, the input to the compressor or combustor is entirely sealed from the atmosphere. This feature is referred to herein as a "closed cycle".

From the foregoing it may be appreciated that the present invention provides an extremely flexible and energy efficient apparatus and method for the production not only of syngas and methanol but also of other important chemical products. It is furthermore apparent from the above that the present invention represents a unique use of gas turbines combined cycles not primarily for the production of electrical energy, but instead as a chemical reaction plant, particularly one which is economically able to manufacture large quantities of synthetic fuel and, in addition, supply electric power and other products such as carbon dioxide and nitrogen, both of which are useful in tertiary oil recovery.

The apparatus of the invention may be operated utilizing a General Electric MS7001E gas turbine in a STAG™-100 system, by-passing the compressor as is illustrated in Fig. 3 herein. The methanol reactor may be state-of-the-art system, and the methanol derived therefrom may be used in a methanol-to-gasoline process such as that operated by Mobil Oil Company and described in an article appearing in "Large Chemical Plants", published by Elsevier Scientific Publishing Company, Amsterdam, Netherlands, and authored by W. Lee, J. Maziuk, V. W. Weekman and S. Yurchalk, all of Mobil Research and Development Corporation, Paulsboro, N. J. 08540. Other processes are known in the art to

convert methanol to gasoline, but the present system assumes the use of the Mobil process.

As presently contemplated, calculated values for such operation will be as follows: Oxygen is received from the oxygen plant and is compressed thereby to a pressure of at least 200 psia. Methane, if obtained from a well head or pipeline is at a high pressure, if above 200 psia its pressure is reduced to 200 psia. If below 200 psia it is compressed to 200 psia before entering the combustor. Steam is extracted from the steam turbine at 200 psia. All of the above constituents are input to the combustor at the following mass flows: CH_4=99 pounds per second (PPS). Oxygen is supplied at a rate of 144 PPS, and steam at 200 psia is supplied to the combustor at a rate of 162 PPS. The amount of oxygen and steam is sufficient to ensure that all the hydrocarbon fuel (methane) is completely reacted at a combustor temperature at 2045°F. The gaseous products produced in the combustor are passed through the load turbine 14 with an enthalpy drop of 528 BTU/lb and the heat recovery steam generator 70. The exhaust constituents and their flow rates on entering the heat recovery steam generator 72 will be CO-118 PPS, CO_2-80.3 PPS, H_2-22.2 PPS, H_2O-181.3 PPS, for a total mass flow of 402.2 PPS at a temperature of 1172.1°F.

The major fraction of the heat loss is in the heat recovery steam generator in which water flowing in the water circuit 74 is converted to steam, at 900°F and a flow rate of 142 PPS. This steam is used to drive steam turbine 60 to produce additional electric power from generator 40. Extraction steam is also taken from the steam turbine to supply steam to the combustor 13.

Water in the exhaust is condensed in condenser 76 and removed and it may be used as input to the steam circuit 74 of HRSG 70. CO, CO_2 and H_2 are processed by compressor 102, cooler 103, and separation tank 104 to remove carbon dioxide in liquid form for enhanced oil recovery. The remaining H_2 and CO are fed to methanol reactor 110 which, by an exothermic process described elsewhere, produces methanol and steam at heater exchanger 112 for use in the steam system. The rate of methanol production will be 163 PPS.

This methanol may be converted into a 74.4 PPS of gasoline by the previously referenced Mobil Oil process. At the same time the process turbine will produce 224 MW of electricity.

The electricity requirements to run the various systems will be as follows:

Oxygen Plant	82.7 MW
Carbon Dioxide Compression	4.7 MW
Compression of CO and H_2 for use in methanol plant	53.5 MW
Total Electrical Use	140.9 MW

Net electrical output will therefore be 224 less 140.9 or 83.1 MW for the gas turbine. Additionally, excess steam produced by heat from the exothermic reaction of the methanol reactor and converted into electricity by generator 40 due to added energy supplied by steam turbine 60 will result in the production of an additional 92 MW of electrical power. Thus the total electrical output of the system as described will be 175.1 MW. This electricity, as mentioned hereinbefore, may be sold at the site of the facility for use in the local utility grid or may be otherwise used.

We are aware of U.S. Patents 2,423,527 — Sleenschlaeger; 2,660,032 — Rosenthal; and 4,121,912 — Barber et al., all of which use a combustor which is associated with an expansion (gas) turbine which drives an electric generator. The combustors of these patents operate as open cycle chemical reactors to change or produce various effluents including at times CO and H_2 but they all differ from this invention in significant features. While our invention utilizes substantially complete reaction of hydrocarbon fuel and produces carbon dioxide carbon monoxide and hydrogen all of which are useful products and further generates its own atmosphere, the foregoing patents utilize incomplete combustion of hydrocarbon fuels and do not use all of the reaction products. In fact all are essentially open cycles and utilize scrubbers, etc., and vent process gas or generated or residual hydrocarbon gas or pipe the same to a user. None is associated with a steam turbine in a combined cycle, and none produces carbon dioxide, carbon monoxide and hydrogen as the only significant and useful desired product of the combustion cycle, and none is useful for production of methanol.

While the invention has been described in detail herein in accord with certain preferred embodiments thereof, many modifications and changes therein may be effected by those skilled in the art. Accordingly, it is intended by the appended claims to cover all such modifications and changes as fall within the true spirit and scope of the invention.

Claims

1. Closed combined cycle turbine apparatus for the production of gaseous reaction products including carbon monoxide and hydrogen for syngas production and comprising:

a) a combustor for the complete reaction of a hydrocarbon fuel in the presence of oxygen and steam;

b) a process turbine adapted to be driven by gases produced by and exhausted from said combustor;

c) heat exchanger means for extracting heat from gases exhausted from said process turbine to produce steam;

d) a steam turbine adapted to be driven at least in part by steam produced by said heat exchanger means; and

e) means for condensing water from the gases exhausted from said process turbine to provide process gases including at least carbon monoxide and hydrogen.

2. Apparatus as claimed in claim 1 and further

including means for combining said carbon monoxide and hydrogen to produce methanol.

3. Apparatus as claimed in claim 1 or 2 and further including an electric generator driven by said process turbine and said steam turbine.

4. Apparatus as claimed in claim 3 and further including means for producing oxygen from atmospheric air, said means being operated by electricity derived from said generator.

5. Apparatus as claimed in claim 4, wherein said oxygen producing means includes motor-driven compressor and refrigeration means for cooling compressed air to separate oxygen therefrom.

6. Apparatus as claimed in claim 5 and further including a compressor for compressing said hydrocarbon fuel and said oxygen prior to their entry into said combustor.

7. Apparatus as claimed in any preceding claim and further including respective means for removing water and carbon dioxide from exhaust gases exiting said heat exchanger means to provide a gaseous mixture that is essentially carbon monoxide and hydrogen.

8. Apparatus as claimed in claim 2 and wherein a methanol reactor reactors hydrogen and carbon monoxide together in an exothermic reaction to produce methanol.

9. Apparatus as claimed in claim 8 and further including means for extracting heat from said exothermic reaction to produce steam from water to further contribute motive fluid for said steam turbine.

10. Apparatus as claimed in claim 2, wherein an electric generator is driven by said steam turbine.

11. Apparatus as claimed in claim 10, wherein the generator driven by the steam turbine is the same generator as is driven by said process turbine.

12. Apparatus for the complete reaction of fuel selected from the group consisting of methane and natural gas in the presence of oxygen and steam and comprising:

a) a combustor adapted to operate at a temperature of approximately 2000—2400°F to cause complete reaction of methane or natural gas supplied thereto in the presence of oxygen and steam;

b) means for supplying methane or natural gas to said combustor at a pressure of at least 200 psia;

c) an oxygen plant including at least a compressor and a motor drive therefor and cooling means to separate oxygen from atmospheric air;

d) a process turbine for receiving gaseous products from said combustor including at least CO, CO_2 and water and to be rotated thereby;

e) an electric generator driven by said process turbine when in operation;

f) a steam turbine adapted also to drive said generator;

g) a heat exchanger adapted to receive exhaust gases from said process turbine and utilize the heat therefrom to convert motor into steam to provide motive fluid for said steam turbine;

h) extraction means on said steam turbine to extract a portion of the steam therefrom to supply steam to said combustor to ensure complete reaction of the methane or natural gas being reacted therein;

i) a condenser adapted to remove exhaust gas from said heat exchanger means and to separate therein water from said gases and provide a mixture of carbon monoxide, carbon dioxide and hydrogen;

j) a carbon dioxide removal system including at least a motor-driven compressor and cryogenic means for liquefying said gaseous mixture and a cold tank adapted to separate carbon dioxide from carbon monoxide and hydrogen as frictional distillates; and

k) a methanol reactor inlcuding at least cooling means to cool said remaining mixture of CO and H_2 to facilitate an exothermic reaction therebetween, while removing said exothermic heat by heat exchange with water in thermal relationship with said reactor to produce steam as further motive fluid for said steam turbine.

13. A method of producing carbon monoxide and hydrogen for the production of methanol using a combined gas and steam turbine combined cycle power plant and comprising the steps of:

a) burning a hydrocarbon fuel and oxygen in the presence of steam in the combustor of said power plant so as to cause complete reaction of said hydrocarbon fuel;

b) passing the products of combustion in said combustor through the load turbine of said plant to cause the production of electric power by the electric generator of said plant;

c) further passing the products of combustion, after passing through said load turbine to pass through a heat recovery steam generator to produce steam to power the steam turbine of said plant;

d) extracting steam from said steam turbine and providing said steam to said combustor for the reaction of said hydrocarbon fuel;

e) further processing the products of said combustion to remove therefrom water and carbon dioxide, and traces of any other gases present leaving only carbon monoxide and hydrogen; and

f) providing said carbon monoxide and hydrogen to a methanol reactor.

14. A method as claimed in claim 13, wherein said hydrocarbon fuel is selected from methane and natural gas.

15. The method of claim 13 or 14, wherein said water is extracted from said products of combustion in a condenser.

16. The method of claim 13 or 14, wherein said carbon dioxide and other impurities are separated from carbon monoxide and hydrogen by compression and refrigeration.

New claims or amendments to claims filed on 10 March 1983.

New or amended claims

17. Closed combined cycle turbine apparatus substantially as herein described with reference to and as shown in any one of the Figures of the accompanying drawings.

18. Apparatus according to claim 12 substantially as herein described with reference to and as shown in any one of the Figures of the accompanying drawings.

19. A method according to claim 13 substantially as herein described with reference to and as shown in any one of the Figures of the accompanying drawings.

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